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Pollution Abatement Costs:
Hurting or Helping Productivity?

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Abstract

This paper analyzes the effect that regulatory inputs or expenditures for labor, materials, and capital have on productivity for three industries (blast furnaces and steel mills, alkalies and chlorine, and petroleum refining). Data is examined from 1973 to 1994 and the growth rate of total factor productivity (TFP) is considered. The pattern of pollution abatement expenditures for three media, water, air, and solid wastes, is also examined graphically. In addition, the measurement for TFP is adjusted to net out regulatory inputs for labor, materials, and capital. A comparison between the original and adjusted measurement of TFP is made for each industry. A one percent increase in capital abatement expenditures causes a .29% decrease in productivity while a one percent in labor abatement expenditures causes a .38% increase in productivity for blast furnaces and steel mills. Combined with results from the TFP comparison in this industry, which revealed that abatement expenditures improved productivity, these results suggest that the positive effect of labor inputs outweighs the negative effect of capital. Significant results at the 95% confidence level were not obtained for alkalies and chlorine or petroleum refining industries. However, abatement expenditures for labor are weakly significant at the 90% confidence level for petroleum refining showing that a one percent increase in labor expenditures causes a .20% decrease in productivity. These results are consistent with the TFP comparison results.

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I. Introduction

Environmental regulations are often benefit-based; when deciding whether to implement a policy officials sometimes only look at the benefits of reducing pollution. However, these laws often come with very large price tags. Because these regulations often impose substantial costs on industries, it has been proposed that these costs also reduce industry competitiveness. In past studies, there has been much debate about the effects that pollution abatement costs have on the productivity of a firm. However, abatement costs are difficult to measure, since certain costs are not easily accounted for on the Pollution Abatement Costs and Expenditures survey. An understatement of the true value of these costs can occur. In addition, calculating productivity for an industry also is a complicated procedure. Hence, the effect of regulations on productivity is uncertain.

Regulations might reduce productivity, but a number of researchers argue that, as a result of their studies, regulations may in fact help productivity by promoting innovation and thus, creating gains in competition. Some reason that if a country supports stricter environmental regulations then the innovation created will cause the U.S. to be a net exporter of newly-developed environmental technologies.

In many historical instances, the predicted costs for a new environmental policy are much higher than the actual costs. For instance, analysts predicted that the Clean Air Act Amendments of 1990 would cost U.S. industries over $100 billion. In fact the costs have been significantly less. A predicted $16.40 per ton cost for the paper and pulp industry actually turned out to be between $4.00 and $5.50 per ton (Porter and Linde, 1995, pg). However, in 1990, $97.88 billion was spent on pollution abatement - $72.26 from the private sector and 25.62 from government spending (Callan and Thomas, 2000, 246). In addition, $1.92 billion was spent on regulation and monitoring in 1990 while $1.52 billion was spent on research and development for abatement purposes (Callan and Thomas, 2000, 246). Hence, even though these costs may be less than their predicted values they are not insignificant.

In this paper, the effects of abatement costs and expenditures, as reported in the Pollution Abatement Costs and Expenditures survey, on total factor productivity will be analyzed for the time period from 1973 to 1994. The effect will be studied for three industries at the Standard Industrial Classifications Index's (SIC) 4-digit level: Blast Furnaces and Steel Mills (3312), Alkalies and Chlorine (2812), and Petroleum Refining (2911). The first section will include background information about both the positive and negative effects that environmental regulations can have on productivity. Explanations of the two main approaches to studying this relationship and information about the three industries will also be given.

In the second section, a more thorough explanation of total factor productivity (TFP) is presented, including a simple example, followed by a review of previous literature. The third section provides details on the datasets being used as well as their limitations. Abatement expenditures for the three industries are studied across three mediums: water, air, and solid waste. Once TFP is calculated for each industry, it is then readjusted to exclude any inputs relating to regulation. This new measure of TFP is compared to the old measure for each of the industries.

The fourth section includes the regressions of TFP on regulatory inputs, econometric issues involved, and the empirical results. A simulation is also completed within the data set to answer the question of how the regression results would change if something in the data were different. The results of the simulation conclude the section. The final section contains some concluding remarks and areas for further research.

II. Background

With environmental regulations, costs relating to abatement technology increase and productivity within the industry can be affected. There are two trains of thought on how abatement costs affect productivity. As Michael Porter argues, regulations stimulate innovations that improve efficiency, productivity, and even competitiveness. However, some find fault with Porter's argument and believe the costs associated with environmental regulation are much greater than thought, causing productivity to decrease. Further information about these two hypotheses and the different ways to study the effects of abatement costs on productivity follow. In addition, a brief overview of the three industries is presented.

Effects of Abatement Costs on Productivity

Positive – "Porter Hypothesis": Michael Porter, a professor at Harvard Business school, supports the idea that environmental regulations may increase firm productivity. His argument is that the opinion that regulations reduce productivity stems from a "static view of environmental regulation, in which technology, products, processes, and customer needs are all fixed" (Porter and Linde, 1995, 365). Porter and Linde describe international competition as dynamic and believe that at the industry level it arises from superior productivity, especially from industries that have the ability to improve and innovate on a continuous basis. Strict environmental regulation can stimulate innovation, and thus enhance competitiveness. Regulation can spawn innovation because firms do not always make optimal choices. This will only hold true in a "static optimization framework where information is perfect and profitable opportunities for innovation have already been discovered" (Porter and Linde, 1995, 366).

According to Porter and Linde, environmental regulation can have several positive effects. Regulation signals potential technological improvements and resource efficiencies, and regulation focused on information gathering can increase corporate awareness. Also, investments addressing the environment will definitely be more valuable once regulations are in place, and with increased certainty there will be increased investment. In addition, pressure from regulations stimulates innovation and progress, while promising that a firm will not become less competitive during its transition to a newer technology.

Porter and Linde also argue for incentive-based policies regarding pollution prevention/control. With market incentives such as tradeable permits, firms are given more flexibility, reinforcing resource productivity, and creating incentives for continuing innovation (Porter and Linde, 1995). Governments should focus on "relaxing the environment-competitiveness tradeoff [and] . . . should shift from pollution control to resource productivity" (Porter and Linde, 1995, 385). In addition, innovation-based solutions are needed that promote both environmental quality and competitiveness.

Negative: Palmer, Oates, and Portney (1995) agree with some of Porter and Linde's ideas but not all of them. Instead they see the potential for environmental regulation to decrease productivity. They agree that government should rely more on incentive-based policies for regulation and also agree that some estimates of compliance costs are often higher due to unforeseen technological advances. Palmer et al. also "acknowledge that regulations have sometimes led to the discovery of cost-saving or quality-improving innovation” (1995, 120). However, on this last point Palmer et al. believe that Porter and Linde’s argument is not strong enough as they simply use case studies to defend their point. Also, Porter and Linde suggest that enlightened regulators can provide the needed incentives for these innovations that competition does not provide. However, this concept of “enlightened regulators” is rather difficult to believe.

Thus Palmer et al. complete their own analysis, taking into account the social benefits of regulations. Comparing marginal abatement cost curves, they find that an “increase in the stringency of environmental regulations unambiguously makes the polluting firm worse off” (Palmer et al., 1995, 125). Even with the new technology the benefits are not high enough to raise the company’s profits after environmental standards are raised.

With regards to Porter and Linde’s argument of new technologies offsetting pollution abatement costs, Palmer et al. find these offsets are actually quite small – “based on both the reports of those who make environmental investments as well as on hard data” (Palmer et al., 1995, 129). In addition, firms usually must project returns exceeding twenty percent before undertaking an investment. Therefore, even if the offsets are dollar-for-dollar, the return on invested capital is still an important cost of regulation. Palmer et al. argue that although regulations can cause societal benefits, ultimately the costs are often greater. In this way, environmental regulations increase excess costs to society and can also reduce productivity in the economy.

Different Methods to Study the Productivity Effect: There are many different ways one can study the effect that environmental regulation has on productivity. The two most common are growth accounting and econometric estimation. In the growth accounting approach, estimates of compliance costs are used to calculate productivity effects. The approach "relies on the neoclassical production theory under constant returns to scale" (Jaffe et al., 2000, 7). Output is estimated as

$$Y = A + \beta_1 L + \beta_2 K + \beta_3 E$$

where the β's equal the corresponding factor shares for labor, capital, and environmental inputs. Thus, productivity is seen as the arithmetic residual (A) after the share-weighted inputs are subtracted from output. Using this approach, studies tend to find that compliance costs are a small part of total cost, so the impact on productivity will probably be small (Gray and Shadbegian, 1995, 2).

In econometric estimation, researchers often use plant-level or industry-level data on regulation costs to test for regulation's impact on productivity. Using time series data the magnitude of A is the "econometric residual after the estimated effects of all measurable inputs on output have been allowed for" (Jaffe et al., 2000, 7). With this approach, studies seem to show that there is a statistically significant effect of regulation on productivity (Gray and Shadbegian, 1995, 2). A further demonstration of this approach will be given later. Although they are not complementary, the results of both approaches suggest that compliance costs can have a small, yet statistically significant, impact on productivity.

Industries in the Study

Chemical – Alkalies and Chlorine (SIC 2812): Establishments in this part of the chemical industry produce basic chemicals and manufacture products through predominantly chemical processes. Chlorine is produced through the electrolysis of salt, where salt and water produce chlorine, sodium hydroxide, and hydrogen. According to Couper et al. (2001), there are dramatic swings in the price of chlorine, resulting in periods when chlorine is produced in quantities greater than demand. In general, the chemical industry is

> “one of the most dynamic sectors of economic life . . . responding to both external forces and internal innovations. No chemical company can feel secure for very long with an established technology or market. Examples abound of chemical products and processes that were once important but are now obsolete or dated.” (Couper et al., 2001, 409)

Chemical companies do not have a guaranteed place in the economy. Thus, in order to stay in the market, chemical companies have become leaders in their reliance on technology and innovation to improve their products and processes. Product innovation in this industry includes new products and new uses for existing products (Couper et al., 2001). Process innovation has led to lower costs and more efficient uses of raw materials.

In addition, chemical companies also have to face complex social factors that affect their fate. Chemical companies have come under attack recently with regards to environmental problems, product liability, and employee health and safety (Couper et al., 2001, 411). The chemical industry in the United States also suffers from “dwindling raw material deposits, very high relative electricity costs, heavily subsidized foreign competitors and other disadvantages that have rendered them uncompetitive” (Porter and Linde, 1995, 377) without regard to environmental factors.

The chemical industry is an important emitter of sulfur dioxide (SO_2), a pollutant regulated by the Clean Air Act (CAA) of 1970 and the CAA amendments of 1977 and 1994 (Greenstone, 2001, 6). Distillation, extraction, absorption, crystallization, evaporating, drying, and steam stripping or cracking are a few of the technologies the chemical industry uses to remove contaminants from their processes (Chemical Industry Analysis Brief, Accessed 3/10/02).

Pollution control and the environmental impact of chemical products will continue to play an important role as we learn more about their effects and improvements in environmental science and engineering are made. Currently, there is a lack of information on various products and their effects on the environment. As these effects become known, stronger legislation on these products is likely to be implemented.

Oil – Petroleum Refining (SIC 2911): The modern oil industry began in the United States in 1859 with the completion of an oil well in Titusville, PA. By the early 1900s, the use of oil began to change rapidly as the price of oil dropped. In addition, industry discovered the use of oil as cheap energy and the switch from coal to oil occurred quickly beginning with the use of oil as a boiler fuel. Within ten years oil production in the U.S. tripled as oil was discovered in Texas, California, and the Midwest (World Health Organization, 1989, 39). Oil continued to be an important resource throughout the 20th century. However, during the late 1970s and early 1980s, oil refining in the western world declined while increasing in less developed countries.

In addition, oil refining has many environmental effects including air, water, and solid waste pollution. As crude oil is refined into products, some of the components are transformed into pollutants. In fact, “refining is one the top five major industrial polluters” (Kerlin and Rabovsky, 1975, 14) and the petroleum industry is first in its emissions of nitrous oxides (NO_X). The industry is second in sulfur oxide (SO_X)

emissions, and third as a source of hydrocarbon and particulate pollution. In addition, the industry's wastewater contains a wide variety of dangerous water pollutants (Kerlin and Rabovsky, 1975, 14).

The major air pollutants of oil refining include hydrocarbons, NO_X, SO_X, carbon monoxide (CO), and particulates. Under normal conditions, few processes directly emit these pollutants into the atmosphere. However catalytic cracking units, sulfur recovery plants, combustion processes, and storage and loading facilities sometimes do emit pollutants. Hydrocarbon pollution mainly comes from storage tanks and loading facilities, while nitrous oxides are often emitted from combustion processes such as heaters, boilers, some catalyst regenerators and flares (UNEP, 1978, 26). Combustion processes are also mainly responsible for SO_X, CO, and particulate pollution as well. The Clean Air Act of 1970 required the Environmental Protection Agency (EPA) to establish primary and secondary national ambient air quality standards for pollutants. In response, oil refineries implemented different technologies and processes to reduce emissions. In eliminating hydrocarbon pollution, plants can discontinue splash loading at distribution points and instead bottom load rail and road tankers. To reduce NO_X emissions, plants modify combustion equipment, decompose the nitrous oxide, or scrub the effluent gases. The first option has proven most effective so far (UNEP, 1978, 28). Also, desulphurization of refinery gas and fuel oil has reduced SO_2 emissions, and CO emissions have been reduced through "CO boilers, which burn the CO to produce steam that is used to power other refinery processes" (Boothe, 1975, 14).

In addition to oil refining causing air pollution, water and solid waste pollution have also been a problem. Water re-circulation in more modern refineries has reduced water pollution, but reducing water use, using in-plant improvements, and good housekeeping have also been effective. Two treatment steps are also often used to reduce water pollution. In the primary treatment sedimentation for suspended solids, gravity separation, and steam strippers are used to remove undissolved oil and volatile compounds. Secondary treatment is implemented for the removal of non-dissolved oil and dissolved organic material. Filtration and oxidation ponds are used in this step after primary treatment has occurred. In reducing solid waste, two major options exist: incineration and land farming or land filling. Incineration technology is well developed with sludges, emulsion and caustic wastes being burned at 700° C (UNEP, 1978, 31).

The use of the above methods to reduce water pollution resulted from the Federal Water Pollution Control Act of 1972. It set the goal that U.S. water bodies be "swimable and fishable" and that by 1985 all pollutant discharges into navigable waters be eliminated. The standards were too strict and the goals have yet to be accomplished. However, with the law, oil refineries implemented sour water strippers to reduce sulphide and ammonia, the segregation of sewers, and the monitoring and repair of surface condensers. Therefore, in the Petroleum Refining Industry, pollution control and prevention is an important aspect of its operation.

Primary Metal – Blast Furnaces and Steel Mills (SIC 3312): Steel making is the result of four main processes. First, coke making is the reduction of metallurgical coal into pure carbon. Second, iron making reduces iron ore into hot molten pig iron. Third, steel-making chemically bonds molten iron and alloys to derive specific properties of steel grades. And finally, in steel forming, hot or cold rolling processes shape reheated steel of appropriate grade and chemical properties into the needed shapes with suitable coatings (Cannon and Armentrout, 1977, 22). In the U.S., the steel industry increased during the early 1900s but has been contracting since the 1960s, as foreign competition has emerged.

The steel industry emits many pollutants into the environment. Ammonia, phenol, and cyanide water pollution in addition to SO_2 air pollution are some of the problems the industry has to correct. According to the *Environmental Steel Update* (1977), there "continued to be a high positive association between legal pressures by pollution control agencies and corporate actions to do so" (14). Initially the air pollution problem was decreased through the retrofitting of gas and dust collection facilities, but as new plants were designed, improved and cleaner production processes were adopted.

Even today, however, air pollution continues to be an important issue for steel making. Much improvement has been made through energy and resource conservation. For instance, many gases given off during production can be a valuable fuel source. Cleaning systems are needed to treat these gases before they can be reused. Through implementation of these cleaning systems, a steelworks can benefit from the "flexibility of a captive energy resource, reducing energy consumption, and the availability of iron containing materials that might be returned to the process, reducing resource consumption" (UNEP, 1997, 66). In addition, four main types of gas cleaning exist: fabric filters, electrostatic precipitators (ESP), wet scrubbers, and dry cyclones.

In addition, recirculating water systems ensure that water is used effectively within the process and help to reduce water pollution. Sources of wastewater include direct and indirect cooling, gas cleaning, scale breaking, pickling, washing and rinsing operations, and rainfall runoff from raw material stockpiles. Although a wastewater treatment plant and pumping system could reduce pollution and allow wastewater to be reusable, it would also result in product degradation and equipment deterioration (UNEP, 1997, 73). Thus several wastewater technologies have been discovered. To remove solids, steel mills and blast furnace plants rely on settling basins, clarifiers, and filtration, while skimming, filtration, flotation, and coalescing filters can be used to remove oil from water. Also, chemical precipitation can remove metals and organics, and biological treatment and carbon adsorption reduces organics.

The implementation of these technologies and the improvement in pollution control in the steel industry has also resulted from a new environmental objective, Integrated Pollution Control (IPC). IPC has developed into Total Environmental Risk Management and focuses on "looking at all impacts simultaneously and addressing the priority areas in a systematic way" (UNEP, 1997, 133). The objective also focuses on preventative rather than end-of-the-pipe solutions. With this new intention, the steel industry is creating solutions to further reduce pollution.

III. Analytical Issues

Several studies of environmental regulation impacts on productivity have been completed. The following will address four studies accomplished recently, including the study by Wayne B. Gray and Ronald J. Shadbegian, which my empirical analysis follows rather closely. However, before discussing previous research on this subject, an explanation of total factor productivity (TFP) is needed. Productivity is defined as output per unit of inputs. Hence, it makes sense for pollution abatement costs to reduce productivity, as there is no increase in inputs, yet most likely a reduction in output. There has been much economic discussion on how to accurately calculate TFP, and therefore an explanation of the developments regarding its formula is included.

Total Factor Productivity

Definition: Total factor productivity (TFP) is defined as the output per unit input. It is also known as the "residual" or "the measure of our ignorance" (Hulten, 1992, 10). One way to describe TFP is as the residual growth rate of output not attributable to the inputs of capital, labor, and other inputs defined by the specific model of TFP being used. TFP is an inherent part of the income flow model learned in a principles economics class. In such a class, one learns that the market determines a price, p, and quantity, Q, of goods that should be produced and sold. Thus, total revenue is p*Q and inputs in the market include capital (K), labor (L), and their respective prices of rent (r) and wages (w). However, to measure the volume of economic activity for this specific price, the addition of w*L + r*K needs to be scaled. Growth accounting involves measuring this scalar and separating the growth of real output into the input component and the productivity component.

Calculating the Residual: Several different methods for calculating TFP have evolved over the years, thus showing the relative difficulty in establishing a precise formula for this measure of output growth. The first mention of TFP was made by Morris Copeland in 1937 with the first empirical implementation of TFP being completed by George Stigler in 1947.[1] One of the issues in deciding how to calculate TFP is deciding whether one should view this scalar of the income identity from the producer's point of view or the consumer's point of view. Often, the producer's side is used, but the consumer side lurks in the background.

A breakthrough was made when Robert Solow connected the production function with calculating TFP in 1957. Solow begins with the usual production function, as

$$Q = A^* f(K,L)$$

where "A" measures the shift in the production function and is often identified with "technical change" (Hulten, 2000, 8). Assuming a Cobb Douglas production function,

$$Q = A * K^{\beta} * L^{1-\beta}$$

and taking the natural log of both sides, therefore looking at changes now, the production function changes to

$$\ln(Q) = \ln(A) + \beta*\ln(K) + (1-\beta)*\ln(L).$$

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[1] Much of the information about the advancement of calculating the residual comes from Hulten (2000).

Thus, from this production function, Solow calculated TFP (the residual) as

$$TFP = \ln(Q) - \beta*\ln(K) - (1-\beta)*\ln(L)$$

where ln(A) equals the growth in TFP. This measure of TFP has been sometimes termed the "measure of our ignorance" simply because it is a residual and therefore includes many components – some needed such as the effects of technical change and innovation and some that are not wanted such as measurement error, omitted variables, aggregation bias, and model misspecification from the given production function (Hulten, 2000, 10).

However, productivity theory advanced even more with the work of Dale Jorgenson and Zvi Griliches. They suggested that careful measurement and correct model specification should rid the residual of unwanted components and accurately represent TFP. When completing their study, Jorgenson and Griliches discovered that the Solow residual disappeared. Luckily, Edward Denison was able to explain the discrepancy in 1972. Much of the divergence was a result of the different time periods under review in each study and also a result of a "capacity utilization adjustment . . . [which] indicated a secular increase between equivalent years in the business cycle" (Hulten, 2000, 16). Although the work of Jorgenson and Griliches combined data development, growth accounting, and production theory, Denison continued to support the use of output net of depreciation while Solow employed gross output in his empirical work. Thus, the "true" method for calculating TFP is still unknown as this complicated measure of the residual is being researched further.

Old Growth versus New Growth: TFP calculations explain economic growth in terms of the production function and marginal productivity. However, TFP is not a theory of economic growth because it does not explain how the inputs (labor, capital, technology) progress over time. However, the residual can be thought of as a "valid measure of the shift in the production function under the Solow assumptions . . . that labor and technology are exogenous factors determined outside the model and that investment is a constant fraction of output" (Hulten, 2000, 31). However, since this measure of TFP assumes that all capital formation is an exogenous explanatory factor, it tends to overstate the role of capital and understate the role of innovation when looking at economic growth. Some of the capital accumulation results from increases in TFP, and thus only a fraction of capital accumulation should be considered as capital's contribution to output growth.

In the endogenous growth theory (new growth), the concept of capital includes human capital and knowledge, and innovation is endogenous to the model. In this model, the marginal product of capital is assumed to be constant instead of diminishing as in the previous model. This constant marginal return causes the induced accumulation effect of capital to continue to infinity. Ultimately, the endogenous growth model points to a productivity slowdown. However, this idea is not consistent with the data. Hence, a method to explain fluctuations in the rate of productivity change is still needed.

Quality of Data: Another issue in measuring TFP includes how to compensate for improvements in the quality of products or the introduction of new goods. The TFP residual measures merely the effect of more goods (which shifts the production function that the TFP formula calculates). The measurement does not include innovation that results in better goods. One way to compensate for this problem is to "measure output in units of consumption efficiency, that is, in units that reflect the marginal rate of substitution between old and new goods" (Hulten, 2000, 38). A problem with this approach, however, is that improvements in product quality are rather subjective. On the other hand, increases in the physical units of a good can be observed. The true quantity of consumption efficiency could be misstated with little means to reject the misstatement.

In studying the effect of efficiency in the actual TFP model, Jorgenson and Domar discovered that the exclusion of efficiency caused two types of measurement error: an error associated with the mismeasurement of capital input and one related to the mismeasurement of investment good output (Hulten, 2000, 41). However, Jorgenson and Domar realized that these two errors cancel each other in steady-state growth, thus leaving the measurement of TFP unbiased. Although this result was obtained, the concept of quality change in products is still one to consider when calculating TFP since "efficiency depends on the rate in which the embodied efficiency increased and the average embodied efficiency of the older vintages of capital stock" (Hulten, 2000, 41).

Top-Down versus Bottom-Up Approach: Finally, in calculating TFP, there are two different methods by which to measure it. One is the top-down approach in which one starts with the TFP of the aggregate economy and "unpeels the TFP residual" (Hulten, 2000, 50) to determine TFP at the industry level. The main complication in calculating TFP with this approach is accounting for intermediate goods. The gross output of goods and the amount of intermediate goods is greatly affected by mergers and acquisitions. Merging firms can transform inter-firm shipments of intermediate goods into intra-firm shipments, therefore eliminating some of the gross output. In addition, intermediate goods cannot be netted out of the calculation of TFP directly since the value of intermediate goods produced does not always equal the amount of intermediate goods used. For example, the following identity exists for firms:

$$p_iD_i + p_i \sum_i M_{i,j} = w_iL_i + r_iK_i + \sum_j p_{j,i}M_{j,i}$$

where D_i is deliveries to final demand for industry i, p_i is the price of those deliveries for that industry, and $M_{i,j}$ are the intermediate goods shipped from industry i to industry j (this is the left hand side of the equation that describes output for industry i). The right hand side of the equation represents inputs to industry i, where w_i represents wages, L_i represents labor, r_i is rents, K_i is capital, $p_{j,i}$ is the price for intermediate goods, and $M_{j,i}$ represents the intermediate goods purchased from other industries . When this identity is summed over all firms to give the aggregate identity we obtain:

$$\sum_i p_iD_i = \sum_i wL_i + \sum_i rK_i = wL + rK$$

Here, total deliveries to final demand are on the left-hand side of the equation, and total value added is on the right-hand side (Hulten, 2000, 51). By looking at the above equations, we observe that at the aggregate level $p_iD_i = w_iL_i + r_iK_i$ does not necessarily hold. This is because the value of intermediate goods produced does not necessarily equal the amount of these goods that are used. A “real value added” approach had been developed to help with this problem, but it too has problems of its own. Thus, calculating TFP with this approach ultimately creates a dilemma.

Instead of the top-down approach to measuring TFP, one could implement the bottom-up approach. This approach starts with TFP measurements at the industry level and builds up to the aggregate economy. However, an important aspect of this approach involves explaining the "observed heterogeneity of plant productivity in terms of factors like R&D spending or patenting, or differences in the financial or industrial structure" (Hulten, 2000, 54). The literature discussing this concept is extensive and aims to solve the problem that "industries are composed of heterogeneous firms operating under conditions of imperfect competition, while the theoretical aggregation conditions required to proceed upward to the level of the macro economy rely on perfect competition" (Hulten, 2000, 55). Therefore, each approach has its own associated problems and the answers to these problems of calculating TFP are still being researched today.

Previous Studies of Abatement Costs

Gray and Shadbegian: In their study, Gray and Shadbegian (G&S) examined the effects of productivity, pollution abatement expenditures, and other measures for environmental regulation for plants in the paper, oil, and the steel industry. Using both data from the Longitudinal Research Database (LRD) compiled by the Center for Economic Studies at the Census Bureau and the Census Bureau's PACE survey, they concentrated on operating costs rather than new capital expenditures. In addition, they collected data on air pollution inspections and total enforcement actions. From the National Emissions Data System (NEDS), G&S also obtained plant-level emissions of common air pollutants including changes in emissions over time.

First, they calculated total factor productivity as the difference between output (Q) and the weighted average of labor (L), materials and energy expenditures (M), and capital stock (K) by

$$TFP = \log(Q) - a_L \log(L) - a_M \log(M) - a_K \log(K).$$

The weight factors had been obtained by regressing changes in Q on changes in L, M, K, and year dummies. However, this estimation of TFP did not account for the use of some inputs for costs such as pollution abatement costs. Thus, G&S adjust TFP through the following calculation:

$$TFP^* = \log(Q) - a_L \log(L-L_R) - a_M \log(M-M_R) - a_K \log(K-K_R)$$

where the R subscript refers to inputs used for regulatory compliance which they obtained from the Pollution Abatement Costs and Expenditures survey in addition to using the Longitudinal Research Database for their other inputs (Gray and Shadbegian, 1995, 10). With this adjusted measure of TFP, G&S estimate several regressions to compare the effect of abatement costs on productivity for the three industries.

Their results reveal that the magnitude of the effect was larger than had been expected. In fact, “comparing productivity growth rates for the three industries, [they] found a substantial productivity decline, with TFP declining by two percent per year” (Gray and Shadbegian, 1995, 13). Regressions for compliance costs included regressions of productivity levels on abatement cost levels, and regressions that included ways to control for plant differences in regulation, costs for compliance, and some plant-specific events. Gray and Shadbegian also modeled for the possibility that plants with more regulation may have to implement specific technology, which would cause abatement costs to be associated with growth rate of the plant. From these regressions, they ascertained that one-dollar greater abatement costs were associated with $1.74 in lower productivity for paper mills, $1.35 for oil refineries, and $3.28 for steel mills. However, smaller relationships between productivity and abatement costs exist within plants over time. Gray and Shadbegian conclude that “it does not appear that regulation imposes productivity benefits large enough to outweigh the measured compliance costs, and [that] this cannot even be rejected if [they] focus on the analysis of productivity changes over time, or otherwise control for unobserved differences across plants” (1995, 20). Overall, plants with higher enforcement, lower compliance, or more emissions (and thus, higher pollution abatement expenditures) tend to have lower levels of productivity.

Jaffe and Palmer: Adam B. Jaffe and Karen Palmer's article, "Environmental Regulation and Innovation: A Panel Data Study," examines the effect of pollution control expenditures on measures of innovative activity and performance in industries over time. They used panel data from the two and three digit SIC industry levels and determined changes in regulation through regulatory compliance costs in previous years. To measure innovative activity in the industries, Jaffe and Palmer used total private expenditures on research and development and the number of successful patent applications by domestic firms in an industry.

The modeling and data for the study included several regressions. Estimates of industry-funded research and development expenditures were regressed on industry value added, government-funded R&D in the industry, and a lagged PACE variable. Value added was included to prevent spurious correlation between R&D and PACE due to the variation of both with industry size. The second regression included the relationship of PACE and patents. "Typically it is assumed that patents are proportional to (unobserved) innovative output, with a constant proportionality that may vary across industries and across time" (Jaffe and Palmer, 1997, 612). Thus, patents were regressed on value added, successful patents in U.S. applications in each year by foreign corporations, and a lagged PACE variable. Jaffe and Palmer noted that due to the "lag between patent application and grant, reasonably complete patent totals by year of application cannot be determined until two or three years after the year in question" (Jaffe and Palmer, 1997, 613).

Their empirical findings differed across two different measures of innovation in the industries. First "lagged environmental compliance expenditures have a significant positive association with R&D expenditures" (Jaffe and Palmer, 1997, 611) when controlling for industry-specific differences. The study also concluded that increases in compliance costs in one time period were associated with increases in R&D expenditures shortly afterwards. Also, Jaffe and Palmer determined that "high-tech" industries were less pollution-expenditure intensive than low-tech industries on average. However, the analysis found that innovative output, as measured by successful patent applications, was not significantly related to compliance costs. In all of the regressions, the coefficient on the lagged PACE variable was not statistically significant.

Jaffe and Palmer's study supports what they call the "weak" version of the hypothesis that environmental regulation will stimulate certain types of innovation. However, they could not say

> "whether this increased R&D is merely an expensive diversion from firms' other R&D efforts, designed to find a way to cope with the burden of regulation, or whether it is evidence of the shock of regulation causing the firms to wake up and think in new and creative ways about their products and processes" (Jaffe and Palmer, 1997, 619)

Berman and Bui: Eli Berman and Linda T. M. Bui study the effect of air quality regulation on the productivity of oil refineries of the Los Angeles Air Basin. Their study uses two approaches. First, Berman and Bui regress abatement inputs on a count of the number of regulations in effect and take first differences. They account for the variation in local environmental regulation between regions, which is the reason for strict regulation of refineries in the South Coast region. The variation in abatement behavior of petroleum refineries induced by local regulation only is studied because this aspect is the relevant question for policymakers.

The second approach studies the effect of regulation on productivity. Berman and Bui allow for the fact that the PACE (abatement expenditures) may not be accurate due to hidden costs or because abatement is productive by ignoring the distinction between abatement and other inputs in the measurement of TFP. Berman and Bui initially calculate total factor productivity as the difference between the value of outputs minus quasi-fixed inputs and variable inputs. Ignoring the distinction between abatement and other inputs in the measurement of TFP, TFP is then recalculated and inputs are measured as the sum of abatement and conventional inputs such as labor, capital services, crude oil, and other materials for the second TFP calculation. They then examine the difference between the first and second calculation of TFP for South Coast refineries compared to refineries in regions without the significant increases in environmental regulation to observe the effects of regulation on productivity.

The results of the showed found "strong econometric evidence that South Coast regulations induced large investments in abatement capital … and found no evidence that these regulations had more than a transitory effect on the productivity of these refineries" (Berman and Bui, 2001, 499). The first regression reported that South Coast refineries expend $3.2 million more annually on abatement investment than other refineries in California and $4.3 million more than refineries in the rest of the U.S. Moving compliance dates up with new regulations adds $3 million while the implementation of stricter regulations contributes $5 million more in abatement investment for the average refinery. Thus, Berman and Bui "infer that regulations force extensive abatement activity on refineries . . . [and] conclude that local environmental regulations cost millions of dollars in lost product, per regulation, for each plant" (2001, 506). With respect to productivity, it increased for the refineries during 1982-1992 by five percentage points more than the national average. Interviews completed with plant managers suggested that these increases occurred due to the redesign process implemented by the need to comply with regulations. Hence, productivity enhancing abatement in the South Coast refineries "is not a fluke, but reflects a statistical possibility result that should not be ignored" (Berman and Bui, 2001, 508). Because abatement costs can sometimes result in positive productivity changes, Berman and Bui feel the debate on the costs and benefits of environmental regulation should be refocused on the benefits of regulation.

Morgenstern, Pizer, Shih: In an attempt to study the relationship between reported environmental expenditures and true economic costs, Richard D. Morgenstern, William A. Pizer, and Jhih-Shyang Shih merge several large data sets containing plant-level information on regulatory expenditures as well as prices and quantities of both inputs and outputs. Their cost model investigation has three steps. First, they set apart expenditures for environmental abatement from other production expenditures. Then they model the production of conventional output and environmental services. Finally, they estimate the cost model and include a variable to account for the effect of environmental expenditures on non-environmental costs.

Morgenstern, Pizer, and Shih discovered that "total production costs rise by eighty-two cents for every dollar of reported environmental expenditures" (1998, 3). With a 95% confidence interval, the cost ranges from negative two cents to positive $1.68. Using a pooled model, estimates consistently illustrate smaller savings and larger additional burdens than the previous model, especially for the petroleum and steel industries. The total economic costs of a marginal dollar of reported environmental expenditures is $2.73 based on this pooled model. Thus, it seems that "comparing differences among plants based on the pooled model, there appear to be additional costs associated with environmental protection but not included in PACE" (Morgenstern, Pizer, and Shih, 1998, 25). In addition, when examining how changes in PACE variables for a given plant cause changes in other production expenditures, they found no evidence of a positive relationship. Therefore, the results were interpreted as an indication that PACE expenditures moderately overstate the cost of environmental regulation. Morgenstern, Pizer, and Shih believe that "the current emphasis on better measurement of the benefits associated with environmental protection ought to be balanced with greater attention to uncertainties about the costs" (1998, 28).

Previous studies tend to show that more empirical evidence is needed before a clear decision on the effect of environmental regulations on productivity can be made. From the results given above, it appears that stricter regulations are related to increased abatement capital and therefore higher abatement costs. Greater environmental expenditures are then linked to increased production costs. In addition, regulations are also associated with greater investments in research and development even though there is no significant relationship between compliance costs and innovation. Finally, some studies show that stricter regulation and increased environmental expenditures sometimes have a negative effect on productivity, implying that “it does not appear that regulation imposes productivity benefits large enough to outweigh the measured compliance costs” (Gray and Shadbegian, 1995, 20). However, other studies show a positive effect, suggesting further research is needed in this area.

IV. Data Description

In studying pollution abatement and its effect on productivity for firms, differences in abatement costs and expenditures can be observed for three main media: water, air, and solid wastes. Using the U.S. Census Bureau's Pollution Abatement Costs and Expenditures Survey, the importance of a certain medium can be illustrated for the three industries of concern, i.e., the primary metal (Blast Furnaces and Steel Mills), chemical (Alkalies and Chlorine), and oil (Petroleum Refining) industries. In addition to the effect of media on abatement costs, the effect of these abatement costs on total factor productivity is also of importance. However, the measure of TFP that has been accessed through the NBER-CES database does not account for abatement costs, and thus the measured inputs will overstate the amount of input actually used in production. Thus, TFP needs to be adjusted, which is explained in the following section.

Pollution Abatement Costs and Expenditures (PACE) Data

Source of Data and Limitations: The PACE Survey has been conducted annually (except for 1987) from 1973 to 1994 by the Environment, Technology, and Innovation Branch of the U.S. Census Bureau's Manufacturing and Construction Division. This survey is one of the main sources of data on pollution abatement expenditures in the manufacturing sector and contains information on manufacturers with twenty or more employees. According to Mary L. Streitwieser, in her evaluation of the PACE data, the distribution of manufacturing establishments "is predominately medium (50-500 employees) and large sized" (1995, 5). So although the number of firms surveyed may not be large, the employment level and value of shipments in the manufacturing sector are well covered. However, the PACE survey has maintained a sample size of approximately 20,000 manufacturing establishments per year (Streitwieser, 1995, 6).

The sample selection for the survey has evolved over time, but in the time period we study it was a subsample proportionate to the size of the Annual Survey of Manufacturers (Streitwieser, 1995, 5). One problem with the sample was that new establishments were often not included and so the sample size tended to decrease with time. In addition, geographic location was never a consideration in determining the firms to be included in the survey. Thus, the methodology results in unbiased statistics, but there is a rather large sample error (Streitwieser, 1995, 8).

Even though the sampling methodology may be unbiased, there are limitations with the PACE data. Some of the statistics do not match those in public reports, perhaps due to a late receipt of the survey. The differences can be substantial, especially at the 4-digit industry level, which this analysis entails, and some data items are "reported [or] edited from imputed data" (Streitweiser, 1995, 14). Although the survey has become more detailed with time, the basic framework of data collection has remained unaltered. However, there is some conflicting industry classification for the 2 or 3-digit level as there was a revision of the SIC in 1982 and 1987. Another problem involves imputed data, usually marked with a flag of M (no such data was implemented in this analysis), and blank data inputs resulting from a lack of disclosure by firms. In addition, the Census will not report data when there are three or less firms for that industry since too much information about the individual firms involved is being revealed.

Finally, measurement error is often a problem with the PACE data. Sometimes the data do not correspond exactly to the variables researchers would like to use. Also, respondents may "deliberately report erroneous information, or fail to report, or miscalculate difficult to identify expenses, or misinterpret the questionnaire" (Streitweiser, 1995, 23). Measurement error of this nature can cause econometric problems, and changes in the instructions of the survey were made to clarify the categories of costs to be reported.

The PACE survey was designed with the objective of providing cross-sectional aggregate statistics. The dataset that has resulted allows for the study of interesting cross-sectional relationships in economics. In this manner, the survey offers useful data for one to study the effects of pollution abatement in the manufacturing sector, but like most datasets it is not without its limitations.

Media Information for Each Industry: For all of the following graphs there are some gaps in the Alkalies and Chlorine industry because firms would not disclose their costs for these years. In addition, the year 1988 for this industry appears to be an outlier due mainly to hazardous and toxic pollutants, although a confirmation from the U.S. Census Bureau was obtained about the accuracy of this data point. In the later regression analysis, a dummy for this year will be included to account for this year.

Water: Figure 4.1 below displays the differences in relative expenditures for water abatement for the specific industries. The expenditures have been scaled by the size of the industry. Expenditures in the Alkalies and Chlorine industry appear to be the greatest, most likely because the environmental problems in this industry have not been completely uncovered. In addition, costs increased in the early 1970’s most likely as a result of compliance with the Federal Water Pollution Control Act of 1972. During the late 1970's and 1980's, the costs for all the industries declined. Petroleum refining costs increased in the late 1980's and 1990's, while the Blast Furnaces and Steel Industry continued to have declining expenditures as the industry contracted.

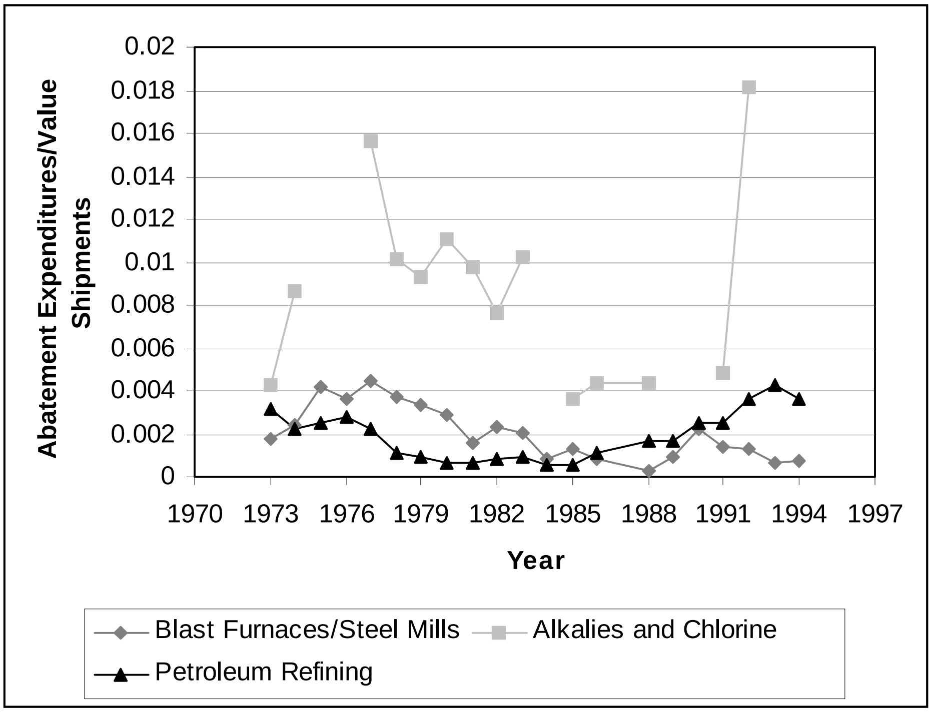

Figure 4.1 Abatement Expenditures for Water Pollution

Air: Figure 4.2 illustrates how air abatement expenditures vary for the three industries. All three industries seem to have expenditures around the same level, excluding the 1988 outlier for the Alkalies and Chlorine industry. A decline seems to occur in the 1980's resulting from compliance with the 1970 and 1977 Clean Air Act Amendments (CAAA). However, the Petroleum Refining industry had an increase in air pollution expenditures during the 1990's, which could be from stricter regulations made by the 1990 CAAA. The Blast Furnace and Steel Mills industry also had a slight increase in the early 1990's but thereafter it declined, most likely after abatement technology was installed and working properly. Also, because the y-axis is measured in relative terms, an increase or decrease in the value of shipments for each variable could also be explaining variation in the graph.

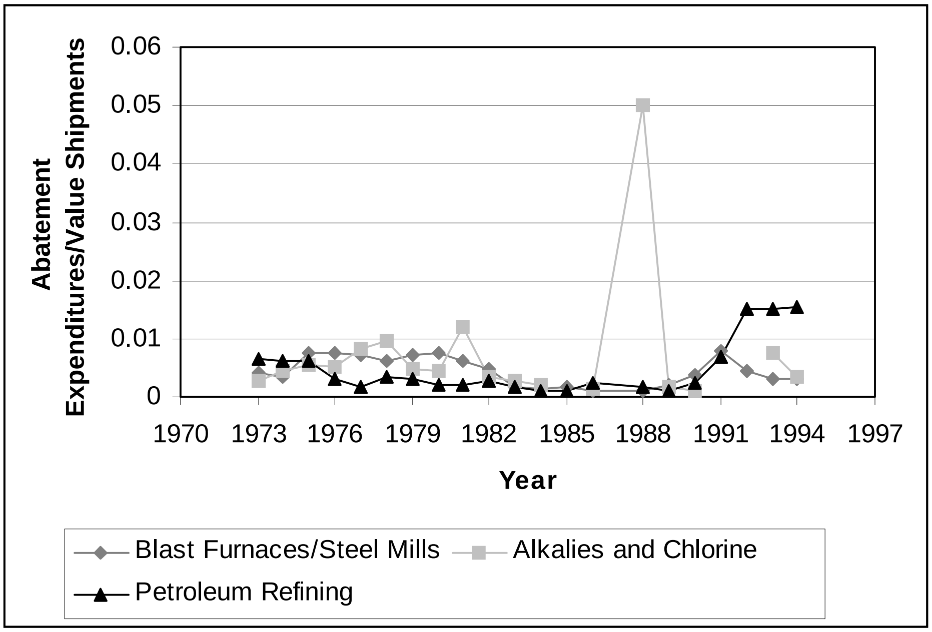

Figure 4.2 Abatement Expenditures for Air Pollution

Solid Waste: A comparison of the industries in their expenditure for solid waste abatement is shown in Figure 4.3. Expenditures for the Alkalies and Chlorine industry are much greater than those for the other industries. This industry has more hazardous waste than the other two industries. With the development of the Resource Conservation and Recovery Act (RCRA) in 1976, which focuses on reducing hazardous solid waste, expenditures were likely to increase. Expenditures were very low for the remaining two industries during the 1970’s and the first half of the 1980’s. However, around 1985 expenditures began to rise for the Petroleum Refining industry and slightly so for the Blast Furnaces and Steel Mills industry. This increase may have resulted from compliance with the regulatory act implemented in 1980 known as Superfund, which had stricter rules for reducing hazardous solid waste.

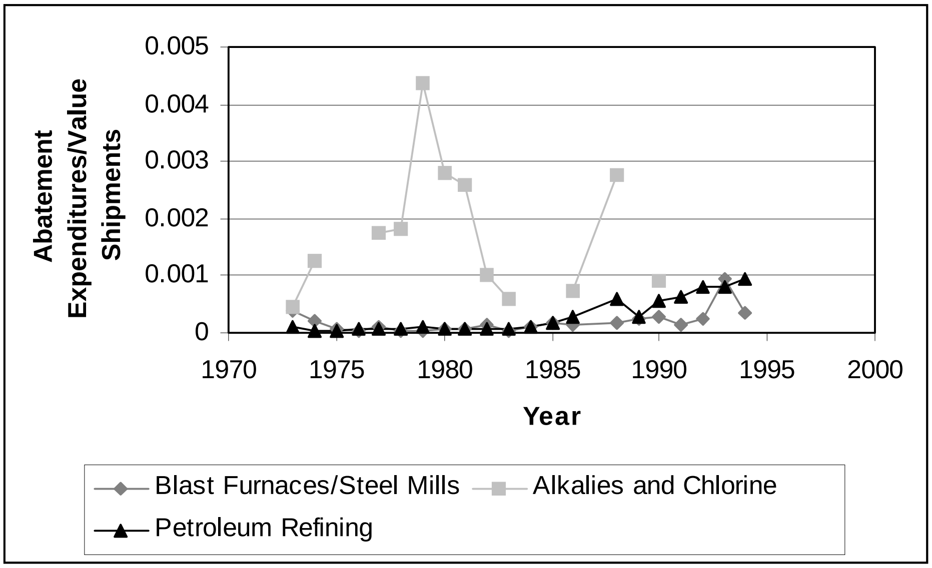

Figure 4.3 Abatement Expenditures for Solid Waste Pollution

Changes in Total PACE for the Industries: From Figures 4.4, 4.5, and 4.6 the distribution of abatement expenditures for air, water, and solid waste pollution in each industry is evident. All the expenditures have been deflated to be real expenditures on abatement, using 1987 as the base year.

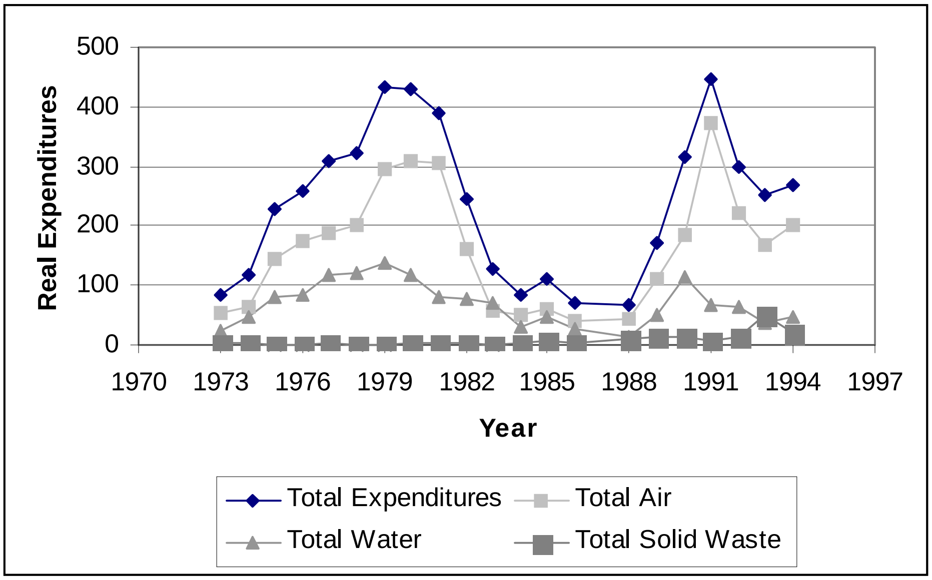

Figure 4.4 Real Abatement Expenditures for Blast Furnaces and Steel Mills

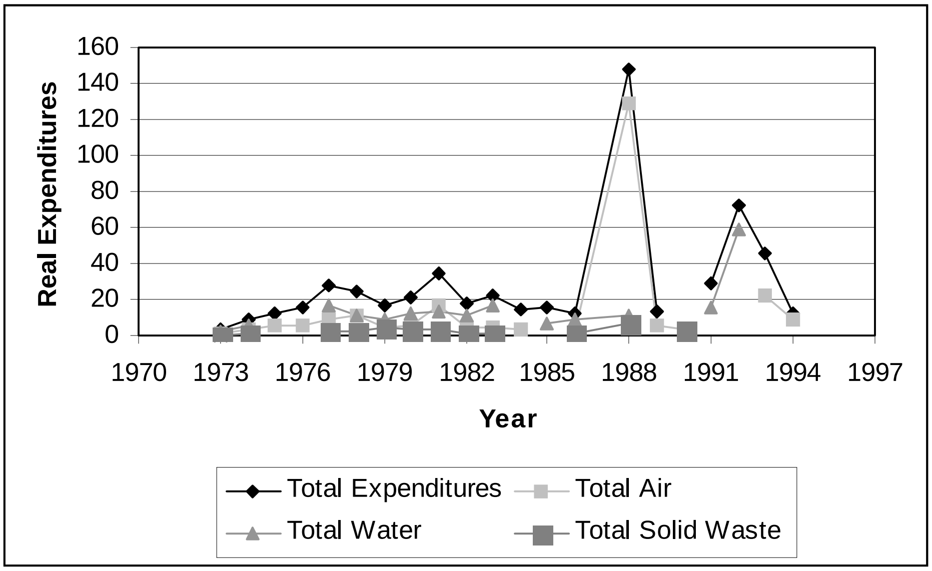

Figure 4.5 Real Abatement Expenditures for Alkalies and Chlorine

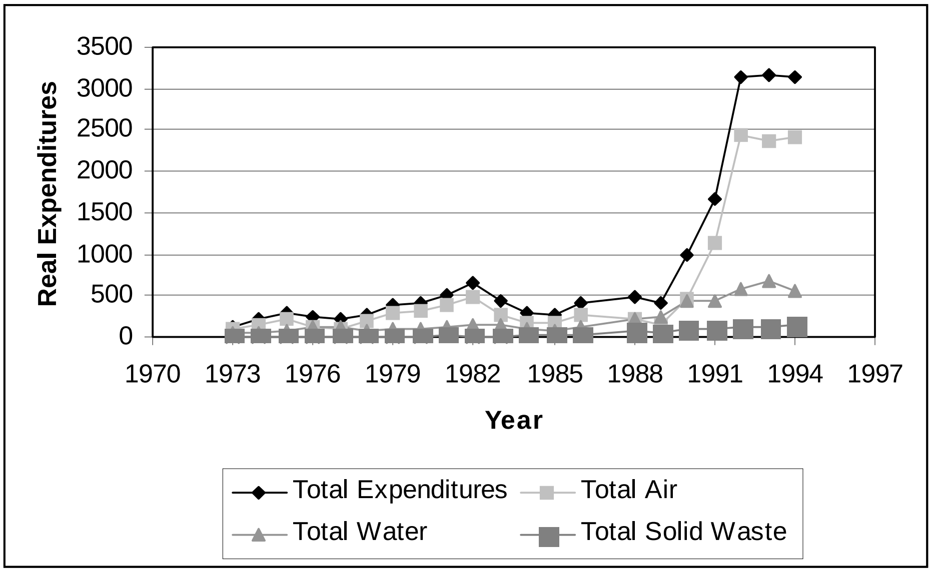

Figure 4.6 Real Abatement Expenditures for Petroleum Refining

Looking at the Blast Furnaces and Steel industry one notices that solid waste costs were minimal in comparison to water and air pollution expenditures. Air abatement expenditures were the highest, and the industry experienced a decrease in expenditures during the 1980s. However, the increase in the 1970s, which peaked just past $400 million returned in the 1990s with a peak of about $450 million in 1991. Eventually costs declined some to approximately $250 million in 1994. The reduction in costs during the 1980's may be because the industry had adjusted to the 1970 and 1977 CAAA and RCRA. Costs increased with the introduction of the 1990 CAAA and Superfund.

For the Alkalies and Chlorine industry, solid waste abatement costs were again the least, but water and air pollution costs trended together during the 1970s and 1980s. Although expenditures were approximately the same (around $10 million) for most of the 1970s and 1980s, there was a sharp increase in 1992 to about $60 million, which decreased to about $10 million by 1994. Since the air pollution costs followed this increase these costs may also be a reaction to the 1990 CAAA. Again the year 1988 is being treated as an outlier.

As in the Blast Furnaces and Steel Mills industry, the Petroleum Refining industry also has the greatest abatement levels for air pollution, with solid waste expenditures being the least. In contrast, however, this industry has much higher levels of expenditures than the other two industries. Expenditure levels for petroleum refining remained somewhat low until experiencing a rise from less than $500 million in 1989 to over $3000 million in 1992. Even though abatement costs have declined somewhat for water pollution by 1994, total abatement expenditures are still very high in comparison to the previous two decades. Most likely these costs resulted from having to comply with the 1990 CAAA since most of these expenditures are the result of air abatement.

When comparing the scaled total abatement expenditures for the three industries, as demonstrated in Figure 4.7 below, one can see that the Alkalies and Chlorine industry had the greatest abatement expenditures while the Petroleum Refining industry had the least until its increase in the 1990's. Blast Furnaces and Steel were slightly greater than the Petroleum Refining expenditures until the latter industry deviated from the other two in the 1990's with a steep increase in abatement costs. By 1994, the petroleum refining industry had the greatest abatement expenditures. Again, the Alkalies and Chlorine industry was mostly responding to the Federal Water Pollution Control Act and RCRA, while increased expenditures for Petroleum Refining resulted from the 1990 CAAA. The Blast Furnace and Steel Mill industry reacted to all these regulations at a more moderate rate.

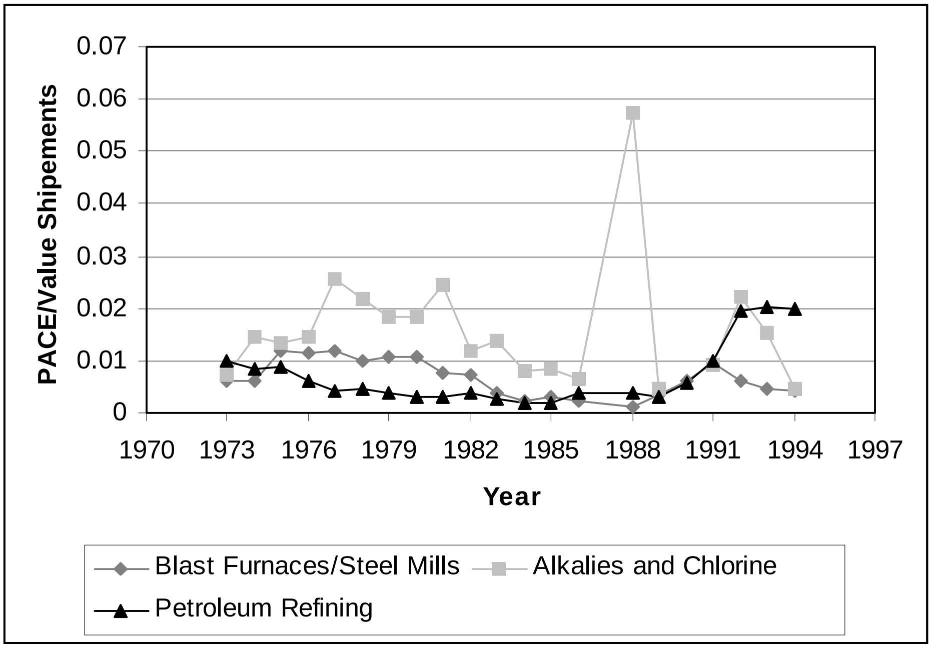

Figure 4.7 Scaled Abatement Expenditures for the Industries

National Bureau of Economic Research (NBER) Data

TFP Calculation in Data: The NBER – CES (U.S Census Bureau's Center for Economic Studies) Manufacturing Industry Database is a joint effort between the NBER and CES, containing annual industry-level data on output, employment, payroll, and other input costs, investments, capital stocks, TFP and various industry-specific price indexes. The database covers all 4-digit manufacturing industries from 1958-1996. However, data is only used from 1973-1994, which corresponds with the time period for the PACE data. Within the NBER-CES database, TFP is calculated based on a five-factor production function, including capital, production worker hours, non-production workers, non-energy materials, and energy. In addition, TFP is also calculated as the "growth rate of output (real shipments) minus the revenue-share-weighted average of the growth rates of each of the five inputs" (Bartelsman and Gray, 1996, 7). The shares were taken from the Annual Survey of Manufacturers on the expenditures for each input, divided by the industry's value of output, or more specifically their value of shipments. Capital share was calculated as a residual (so that the shares add to one), and the labor inputs are measured as the number of production worker hours and number of non-production workers. In addition, expenditures on energy and non-energy materials have been deflated by their respective deflators, which are also included in the database. Deflating all the data variables allows one to have each variable been in comparable dollars (dollars that are for the same year). With deflated variables inferences from comparisons between variables are more justified. Finally, the capital stock growth rate was used to calculate capital input growth.

TFP vs. Macro-Variable: Figure 4.8 illustrates the relationship between growth in TFP (calculated from this study) and year-to-year percent changes in real GDP over the time period being studied. Although all the productivities seem to remain around some constant, it will be shown later that productivity does vary around this constant from year to year. In contrast GDP fluctuates somewhat with dips in the early 1970s, in 1981-1982, and in 1991, which corresponds with recessions in the economy. Therefore it does not appear that productivity trends with the business cycle.

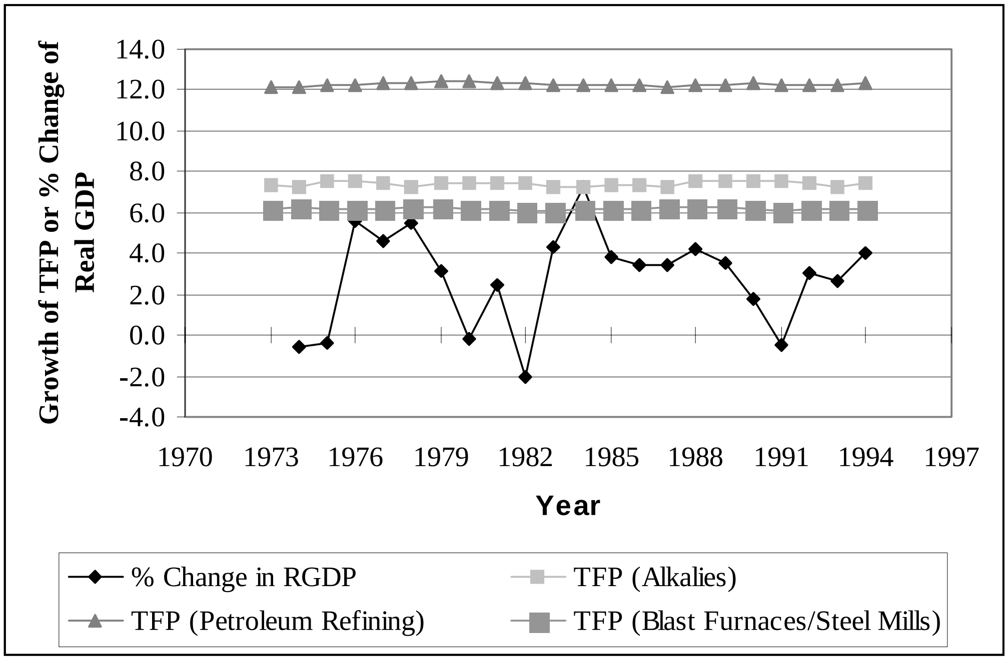

Figure 4.8 Comparison of TFP for Industries and Percent Changes in Real GDP

Adjusting TFP for PACE: As mentioned earlier, the calculation of TFP in the NBER-CES database does not account for pollution abatement costs. Thus, in order to be able to appropriately study the effect of abatement expenditures on TFP at the industry level, the calculation of TFP needs to be adjusted for these pollution prevention costs. In the GS-model, they calculated TFP themselves as:

$$TFP = \log(Q) - a_L \log(L) - a_M \log(M) - a_K \log(K) \qquad (1)$$

They obtained the weight factors, a_L, a_M, and a_K from regressing log(Q) on log(L), log(M), and log(K) and year dummies (denoted in matrix D below) as:

$$\log(Q) = C + a_L \log(L) + a_M \log(M) + a_K \log(K) + a_D D$$

Having the weights, G&S obtain the adjusted TFP by subtracting out the labor, material, and capital inputs used for regulatory compliance denoted by R by calculating:

$$TFP = \log(Q) - a_L \log(L-L_R) - a_M \log(M-M_R) - a_K \log(K-K_R)$$

Using the data available from the NBER-CES database for Q, L, M, and K (combining non-energy materials and energy into M and production worker hours and non-production workers into L to comply with the three factors in the PACE dataset) each of the variables is deflated, using 1987 as the base year. As G&S did, the weight factors on each variable can be estimated by

$$\log(Q) = C + a_L\log(L) + a_M\log(M) + a_K\log(K)$$

where C is a constant. Year dummy variables and terms to correct for autocorrelation were added where necessary (autocorrelation will be discussed later). The results for each industry, with standard errors in parentheses, are as follows:

Blast Furnaces/Steel Mills: (2)

$$
\begin{array}{llllll}
\log(Q) = 4.147333 & + .255162*\log(L) & + .719175*\log(M) & - .291029*\log(K) & R^2 = .989 \\
(2.667) & (.147) & (.085)* & (.197) & \mathrm{BG}\ |p=.83| \\
+ .951354*MA(1) & & & & \\
(.036)* & & & &
\end{array}
$$

Alkalies and Chlorine:

$$
\begin{array}{llllll}
\log(Q) = 7.400409 & - .113304*\log(L) & + .980360*\log(M) & - .799262*\log(K) & R^2 = .973 \\
(4.919) & (.281) & (.195)* & (.600) & \mathrm{BG}\ |p=.68| \\
+ .142902*D88 & + .577845*MA(1) & & & \\
(.103) & (.210) & & &
\end{array}
$$

Petroleum Refining:

$$
\begin{array}{llllll}
\log(Q) = 12.30046 & + .142181*\log(L) & + .947495*\log(M) & - 1.160022*\log(K) & R^2 = .996 \\
(5.463) & (.116) & (.045)* & (.559)** & \mathrm{BG}\ |p=.94| \\
+ .678534*AR(1) & & & & \\
(.222)* & & & &
\end{array}
$$

Here, AR(1) and MA(1) correct autocorrelation problems while a dummy is included for the Alkalies and Chlorine industry to adjust for 1988, which is an outlier. Autocorrelation can occur in data when the error from one time period is correlated with the error from previous time periods. This type of problem can lead to biased estimates as an assumption of ordinary least squares is that the error terms are not correlated with one another. Including an autoregressive term (with one lag) will correct this problem by incorporating the residual from the past observation into the regressive model for the current observation. The program then changes the model from

$$y_t = X_t \beta + \mu_t$$
$$\mu_t = \rho\mu_{t-1} + \varepsilon_t$$

into

$$y_t = \rho y_{t-1} + (X_t - \rho X_{t-1})\beta + \varepsilon_t.$$

The moving average term (MA(1)) also helps correct autocorrelation by using lagged values of the forecast error to improve the current forecast. The first-order forecast error, as used in the above regressions, uses the most recent forecast error. The error term is then computed as

$$\mu_t = \varepsilon_t + \theta_1\varepsilon_{t-1}$$

and is included in the regression where θ represents the coefficient for forecasting the previous error. The Breusch-Godfrey test can be used to see if autocorrelation exists in a model with the null hypothesis of no serial correlation. By the p-values reported above, we can see that we fail to reject the null hypothesis at the 95% level, and therefore any serial correlation problems have been successfully corrected.

The regressions illustrate that materials seems to be driving output since its coefficient is significant at the 95% level for all three industries, and capital in all three industries actually has a negative effect on output. The reason for this occurrence in the steel industry may be because the industry is contracting and so an overstock of capital exists that perhaps is not even used. In the Alkalies and Chlorine industry, stockpiling could also be a problem in addition to the fluctuation of firms that occurs in the industry as discussed earlier. Their industry had a negative coefficient on labor as well, although it is not significant. The petroleum industry also has a negative relationship between capital and output, which is weakly significant at the 90% level and could be the result of foreign competition. In addition, the coefficient on labor is not statistically significant in any of the industries, suggesting perhaps that labor was not measured accurately by the PACE survey.

With the weights needed for each industry, adjusted TFP, called TFP*, can easily be calculated by the next equation:

$$TFP^* = \log(Q) - a_L \log(L\text{-}L_R) - a_M \log(M\text{-}M_R) - a_K \log(K\text{-}K_R) \qquad (3)$$

where the variables with R subscripts refer to inputs used for pollution abatement for each industry as reported in the PACE survey (and deflated as well). An adjusted TFP is one method of determining the effect of PACE on TFP for each industry.

Change in TFP for Industries: Before completing regressions, it is important to illustrate how TFP* changes for each industry during the time period of 1973-1994. The trend in TFP, TFP* (labeled TFP_ADJ), and TFP vs. TFP* for each industry is illustrated in the Figures 4.9 – 4.17. Years are on the horizontal axis and the growth in TFP or TFP* is on the vertical axis for each graph.

From the figures, notice that the fluctuations of TFP and TFP* are within a fairly narrow range for both the Blast Furnace and Steel Mill industry as well as the Alkalies and Chlorine industry. However, TFP* for the Blast Furnace and Steel industry is much lower than TFP, implying that abatement expenditures improved productivity in this industry. Without regulatory inputs (as shown in TFP*) productivity was lower. This result could occur because the industry is a contracting industry, and therefore, changes in technology and location are very different as time progresses. With technological improvements from regulation then, productivity may be enhanced. In the Alkalies and Chlorine industry TFP* is just above the graph of TFP and they follow the same pattern. Therefore, regulatory inputs in this industry seem to be reducing productivity slightly, although not by much. Expenditures for environmental costs may not be as damaging because the effects of this industry on the environment are still being discovered.

In Figures 4.15 – 4.17, the behavior for TFP and TFP* is shown for the Petroleum Refining industry. In this industry, as in the Alkalies and Chlorine industry, TFP* follows the same pattern as TFP although the gap is slightly bigger. The Petroleum Refining industry does have higher rates of pollution resulting in higher abatement costs. However, the industry is older and still competitive so the abatement technology is more prevalent while productivity will not be hurt as much by environmental costs as in the Blast Furnaces and Steel Mills industry. However, one can notice an “S-shaped” trend in TFP and TFP* in this industry as productivity increases, decreases for almost a decade, and then increases again. Perhaps this shape arises because the industry is one without a very large domestic market. In addition the dip could be the product of changes in energy prices.

After reviewing how pollution abatement expenditures are distributed and how each industry under study varies with respect to each medium, one can note that the expenditures vary from industry to industry. The Petroleum Refining and Blast Furnaces and Steel Mills industries have mostly air pollution costs, while the Alkalies and Chlorine industry also has significant water pollution expenditures. In addition, the adjustment of TFP revealed a trend within the Petroleum Refining industry and demonstrated that the

Steel Mills industry has had the greatest change from TFP to TFP*. The average change in the growth of productivity (in absolute value) was 1.95 and in this industry costs from regulations improved productivity. Also, the Alkalies and Chlorine industry had little change between TFP and TFP*, with an average growth change of .0095, and TFP fluctuated from year to year. With this information about costs in relation to media and the effect of abatements costs on reducing TFP to TFP* one can see patterns within the industries. Now we can continue to study the effect of these pollution abatement costs and expenditures on TFP for the three industries by looking at the effects of regulatory inputs.

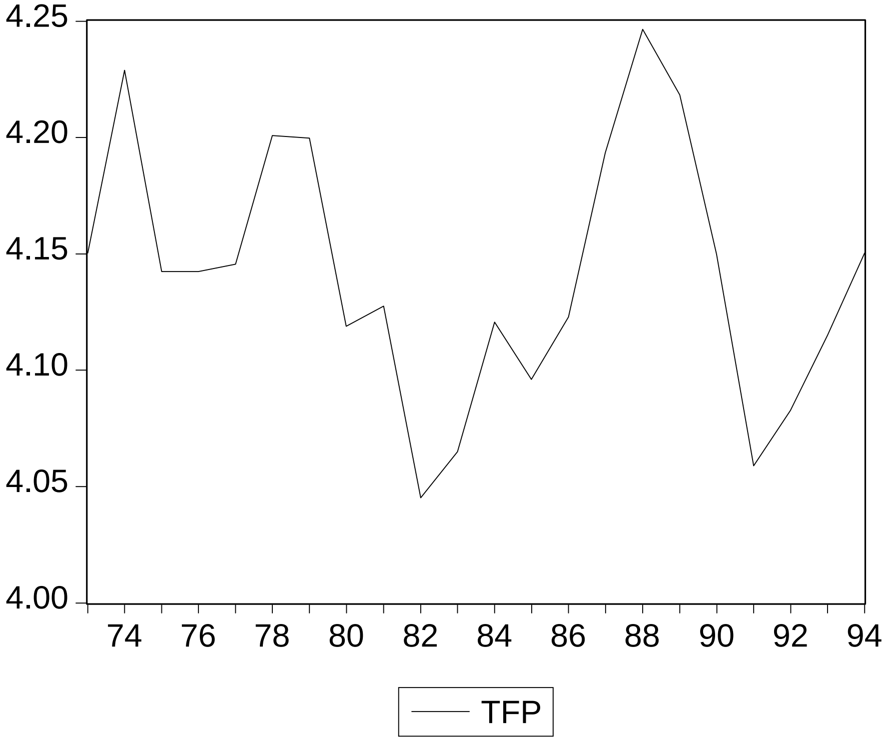

Figure 4.9 TFP for Blast Furnaces and Steel Mills

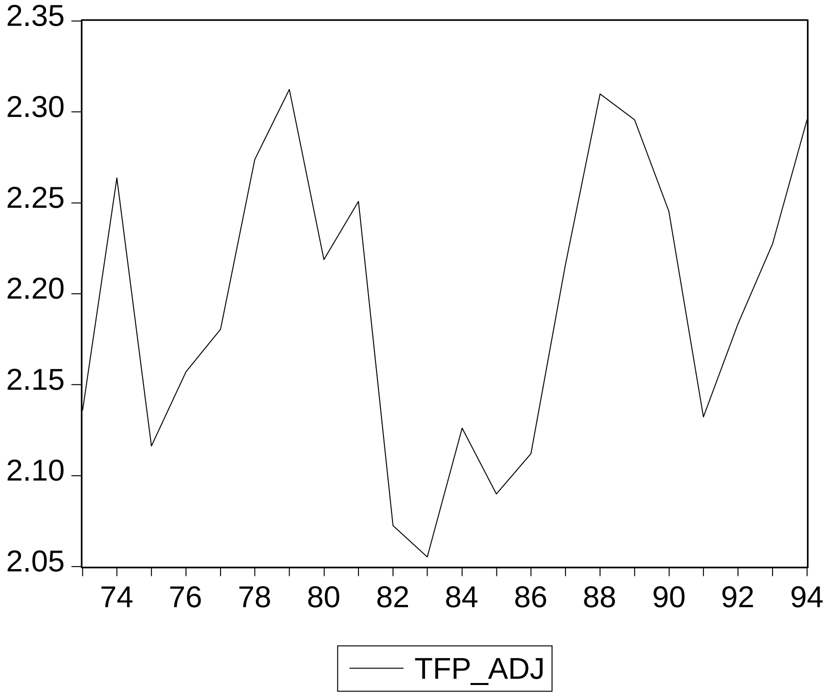

Figure 4.10 TFP* for Blast Furnaces and Steel Mills

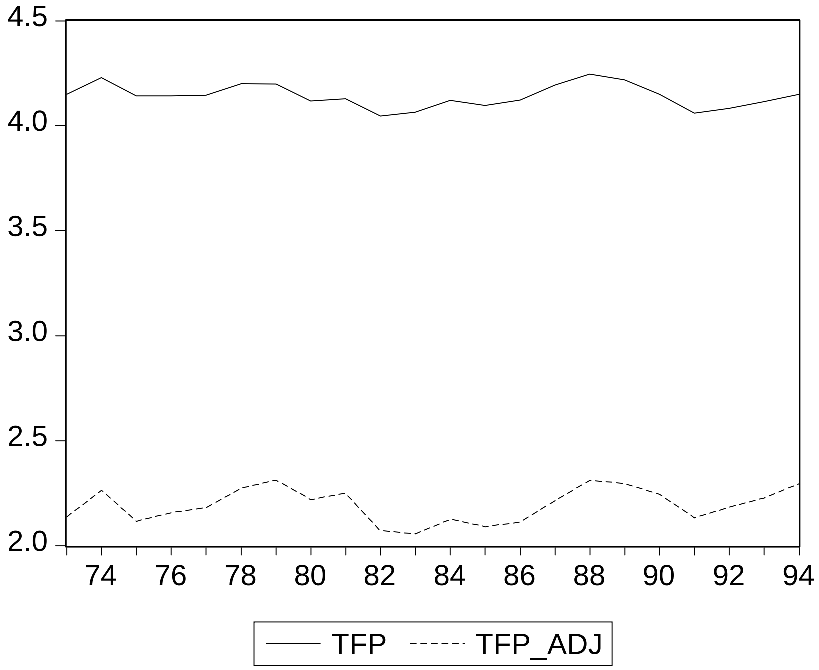

Figure 4.11 TFP vs. TFP* for Blast Furnaces and Steel Mills

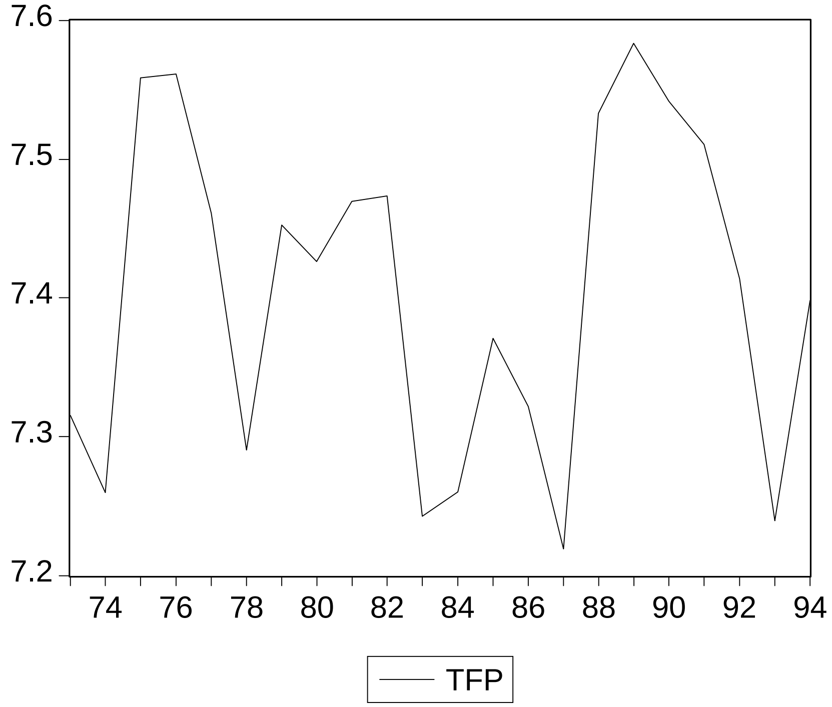

Figure 4.12 TFP for Alkalies and Chlorine

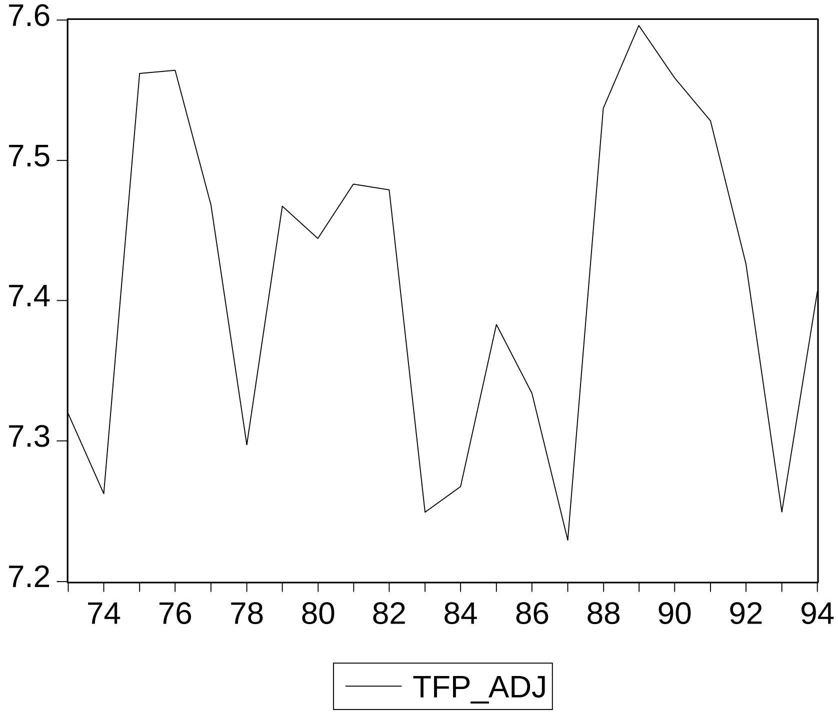

Figure 4.13 TFP* for Alkalies and Chlorine

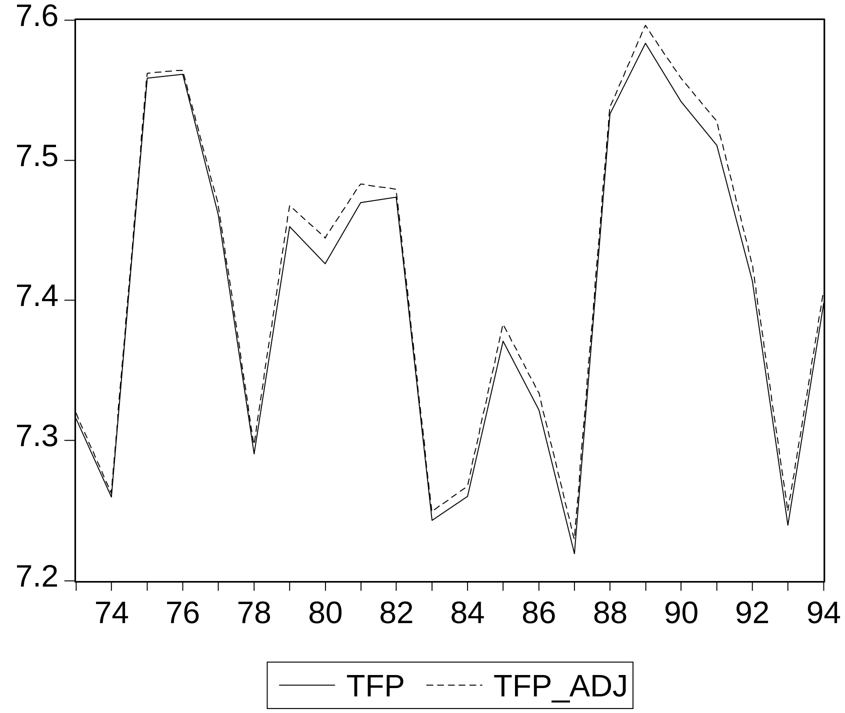

Figure 4.14 TFP vs. TFP* for Alkalies and Chlorine

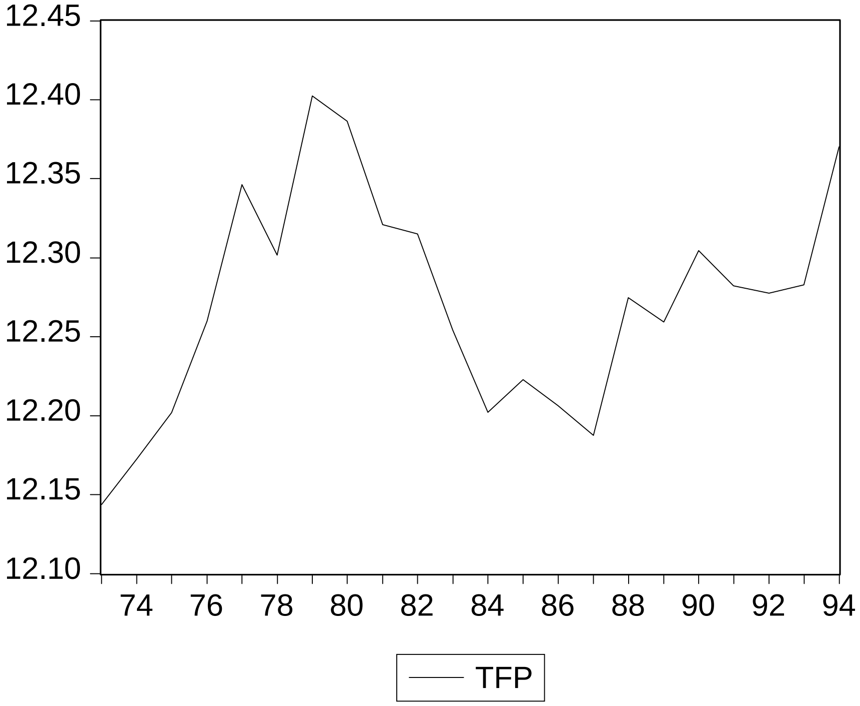

Figure 4.15 TFP for Petroleum Refining

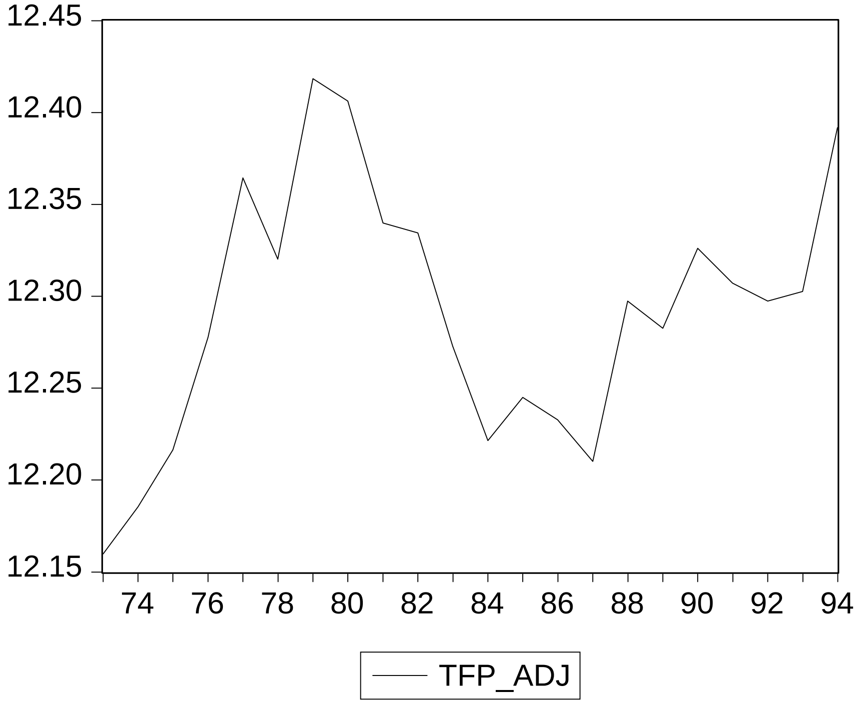

Figure 4.16 TFP* for Petroleum Refining

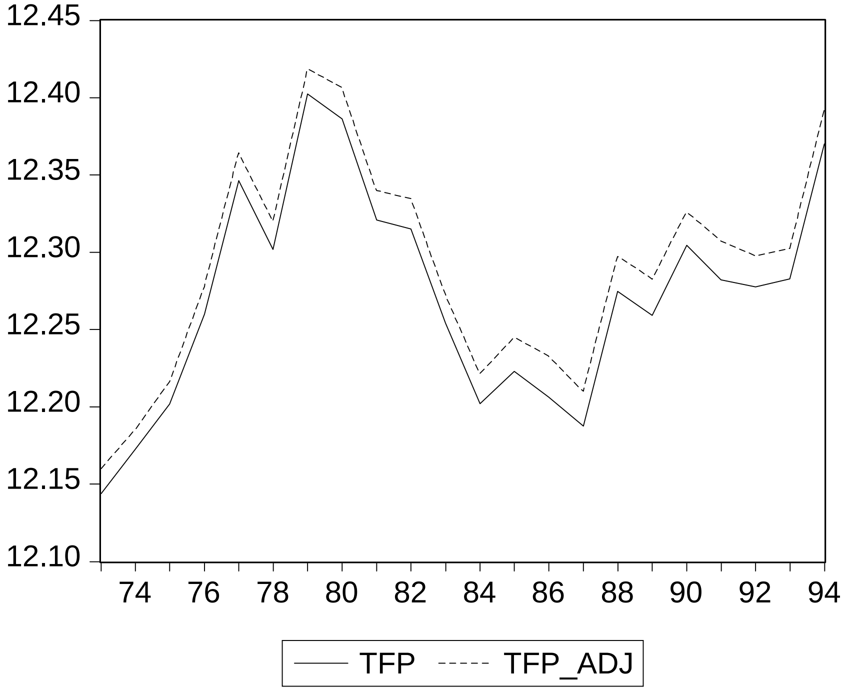

Figure 4.17 TFP vs. TFP* for Petroleum Refining

V. Data Analysis

In addition to looking at an adjusted TFP, which we called TFP*, one can also study the effects of pollution abatement expenditures on TFP through regression analysis. Some econometric issues revolve around time-series regressions and will be discussed below. In addition, a within sample simulation is completed and its results are presented as well.

Methodology

GS Model: In adjusting TFP we first calculated weight coefficients by regressing changes in output (Q) on changes in labor (L), materials (M), and capital (K). Using these weights from equation (2) in the previous section, TFP can be calculated as:

$$TFP = \log(Q) - a_L\log(L) - a_M\log(M) - a_K\log(K).$$

As G&S do in their paper, we can then continue by regressing TFP on regulatory inputs from the PACE survey for the industries specified.

Econometric Issues: Some issues relating to these regressions arise and are of concern. First, there may be greater errors in regression coefficients for the Alkalies and Chlorine industry because several years do not have data due to disclosure problems. Also, firms are not homogeneous. Thus, looking at the industry level, we assume heterogeneity of firms and this may lead to greater error in our coefficients. Problems that often occur with time-series data include unit roots, autocorrelation and heteroskedasticity. Unit roots occur when the mean and autocovariances of the series depend on time, in which case the series is called nonstationary. Having a stationary data series is one of the assumptions for linear regression. Therefore, unit roots can be tested for using the Dickey-Fuller test and unit roots can be corrected by differencing the data series. Autocorrelation can easily be detected by the Breusch-Godfrey test as mentioned previously and can be corrected by quasi-differencing the model or using a autoregressive or moving average term (see previous section for discussion). Heteroskedasticity can be detected through White's test and can be corrected by using White's standard errors. Both problems will be addressed in the regressions below.

Regressions: First, a regression of TFP on regulatory inputs was run, correcting for autocorrelation where needed and adding a dummy variable for 1988 in the Alkalies and Chlorine industry. Then, TFP was regressed on the natural log of total regulatory expenditures for each industry. Again autocorrelation variables were inserted where needed. All inputs were deflated using 1987 as a base year. The results are given in the following tables with standard errors listed below the coefficients in parenthesis. One star signifies statistical significance at the 95% confidence level while two stars represents significance at the 90% confidence level – both with a two-tailed test where the null hypothesis is the coefficient equals zero.

Unadjustd TFP on Regulatory Inputs

Variable	Blast Furnaces/Steel Mills	Alkalies and Chlorine	Petroleum Refining
c	4.441199 (0.232)*	7.324833 (0.158)*	12.15568 (0.130)*
log(labor_reg)	0.381404 (0.116)*	-0.116865 (0.080)	-0.196121 (0.110)**
log(material_reg)	-0.11057 (0.087)	0.147571 (0.107)	0.051306 (0.049)
log(capital_reg)	-0.286045 (0.059)*	-0.069134 (0.133)	0.156585 (0.097)
D88		0.264365 (0.084)*	
MA(1)		0.91331 (0.121)*	0.823945 (0.272)*
AR(1)	0.433721 (0.162)*		
R^2	0.741	0.401	0.574
B-G p value	0.84	0.21	0.30

Table 5.1 Results of Regressing TFP on Regulatory Inputs

Variable	Blast Furnaces/Steel Mills	Alkalies and Chlorine	Petroleum Refining
c	4.429103 (.301)*	7.387446 (.147)*	12.27152 (.457)*
log(PACE)	-0.043401 (.045)	0.003631 (.040)	0.003829 (.059)
D88		0.142245 (.094)	
MA(1)		0.57605 (.199)*	
AR(1)	0.455765 (.214)*		0.678711 (.196)*
R^2	0.321	0.251	0.499
B-G p value	0.09	0.7	0.97

Table 5.2 Results of Regressing TFP on Total Regulatory Expenditures

Incorporating a time trend variable in the above regressions did not make any more of the coefficients statistically significant or greatly improve the R^2 and so the results are not included.[2]

Results

From the previous section and our analysis of TFP here, we can see that TFP varies around some constant for each industry. In addition, materials accounted for much

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[2] In addition, lagged values of the PACE variable were included in each regression. However, this variable did not change the significance of any of the coefficients in the regression and implementing such a term often leads to collinearity problems. Also, lagged values of the dependent variable were used in regressions for each industry. In this case, the coefficient on this lagged term was statistically insignificant for Blast Furnaces and Steel Mills, weakly significant for Alkalies and Chlorine at the 90% confidence level and significant at the 95% confidence level for Petroleum Refining. However, the coefficient on PACE remained statistically insignificant for all three industries and implementing the lagged dependent variable corrected for serial correlation in that we were able to eliminate the AR(1) or MA(1) terms. Because we are interested in the effect of PACE on TFP these results were not included above.

of output in all the industries, having highly significant coefficients. As a result, the residual is small, allowing little room to explain productivity. Therefore any significant coefficients in the above regressions are rather important. In the regressions regulatory expenditures on labor include salaries and wages for labor needed to supervise or implement the new technology, while regulatory expenditures for materials includes such things as fuel, electricity, contract work and services, and leasing of new materials or additional space. Of course, regulatory capital expenditures include the new capital needed to meet compliance deadlines.

By regressing TFP on regulatory inputs we realize that environmental costs can have a negative effect on productivity. In the Blast Furnaces and Steel Mill industry, we find that capital and labor regulatory inputs have a statistically significant effect on productivity at the 95% level. Labor, in fact, has a statistically significant positive effect in this industry. For a one percent increase in capital expenditures for abatement productivity decreases by .29%. This percentage may seem insignificant but recall that productivity fluctuates around a constant varying by only .3 (see Figure 4.9). In addition a one percent increase in labor costs for compliance results in a .38% increase in productivity. Since this industry is a contracting industry, capital investments are declining. Therefore, having to increase capital for abatement purposes would likely hurt productivity whereas useful labor could contribute to productivity. Recall our results from the previous section, where TFP* was significantly less than TFP suggesting that environmental costs had a positive effect on productivity in this industry. Therefore, it would appear that positive effects of labor regulatory inputs outweigh the negative effects that capital regulatory inputs have on productivity.

In the Alkalies and Chlorine industry, none of the coefficients on regulatory inputs are statistically significant at the 95% or 90% level. significant at the 90% level. Inferences cannot be made as easily from this industry for a couple of reasons. The chemical industry changes quickly and its effect on the environment is still being discovered. In addition, this industry did not disclose much of their data points in the PACE survey which could also interfere with any interpretations. This result also corroborates our results on TFP* in the previous section. In this industry, TFP* was very close to TFP implying that regulatory costs did not have a great impact on productivity.

Similar to the Alkalies and Chlorine Industry regression, the Petroleum Refining regression does not have very strong results either. In this industry, labor expenditures are weakly significant at the 95% level. A one percent increase in labor expenditures for environmental compliance produces a .20% decrease in productivity. Again, this decrease is important as TFP fluctuates between a growth rate of 12.1 and 12.45 (see Figure 4.15). The Petroleum Refining industry saw a wider gap between TFP and TFP* suggesting that productivity declined due to compliance costs. This industry's TFP also had a slight problem with unit roots, but we were unable to obtain significant results from the regression anyway.

In addition to showing that there is both positive and negative effects on productivity, the regressions also have a low R-squared. This results because many other variables affect productivity besides regulatory costs for labor, materials, and capital. Also, the regressions of TFP on total regulatory expenditures do not have any statistically significant coefficients on the regulatory costs (at the 90% and 95% levels) and so no further discussion of them is presented here.

Within Sample Simulation and Results

Besides completing regressions it is sometimes of interest to ask what would happen to one's results if something within the data were to change. For instance, looking at Figure 5.1 we can see the difference in the growth of regulatory costs for labor, materials, and capital in the Blast Furnaces and Steel Mills industry. Growth in capital compliance costs drops in 1988. What if the growth rate had remained at this level through 1994? By repeating our previous regression using this new value of regulatory capital inputs, called K_R*, we see that new TFP (labeled as TFP_SIM) varies from TFP in Figure 5.2. In our previous regression regulatory capital costs had a negative effect on productivity, but overall we saw that regulatory inputs had a positive effect on TFP. Thus, by leveling regulatory expenditures on capital at this lower level from 1988-1994 we would expect that TFP_Sim would be higher than TFP for this time period. More clearly our previous regression estimated:

$$TFP = C + a_R \ln(L_R) + a_M \ln(M_R) + a_K \ln(K_R) + \rho AR(1) \qquad (1)$$

We create a new series for capital, made constant for 1988-1994, call it K_R* and calculate:

$$TFP\_Sim = C + a_R \ln(L_R) + a_M \ln(M_R) + a_K \ln(K_R^*) + \rho\mu_{t-1} \qquad (2)$$

Comparing the fitted value of (1) with the new generated series from (2) we obtain the results expected as shown in Figure 5.2. Therefore, by having decreased regulatory inputs than what actually occurred, positive effects on productivity become somewhat larger.

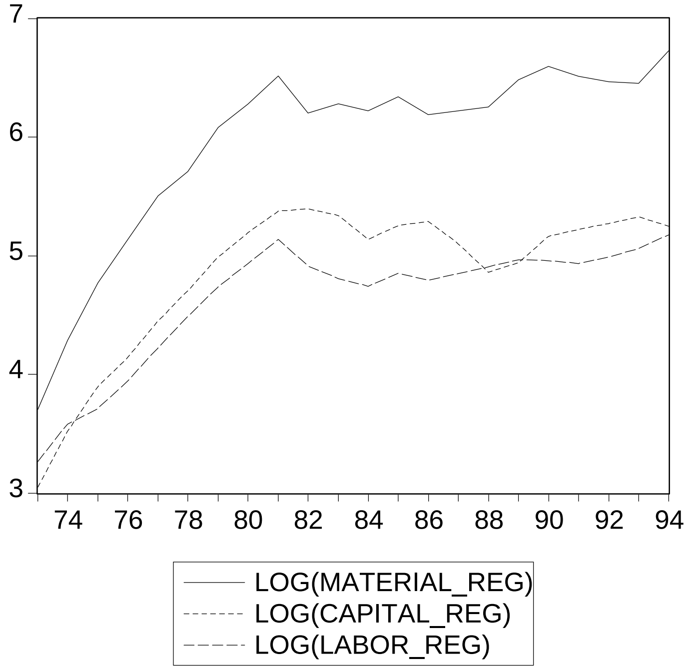

Figure 5.1 Growth in Regulatory Inputs for Blast Furnaces and Steel Mills

Figure 5.2 TFP vs. TFP_Sim for Blast Furnaces and Steel Mills

VI. Conclusion and Further Research

Regulations regarding environmental policy have many effects. Mostly, they are designed to benefit society by reducing pollution. However, costs are also associated with these regulations. How these environmental laws and abatement costs affect productivity is still under debate. Some believe that if resources are used for abatement then those inputs are an extra cost and must decrease productivity. Others find that environmental laws promote the creation of technologies that allow firms to be more competitive and efficient.

As the result of laws such as the Federal Water Pollution Control Act, the Clean Air Act, RCRA, and Superfund, abatement expenditures for the Blast Furnace and Steel Mills (SIC 3312), Alkalies and Chlorine (SIC 2812), and Petroleum Refining (SIC 2911) industries have increased. In addition, these expenditures have resulted in reduced TFP when subtracting out the inputs used for regulation (TFP*). Regressing TFP on regulatory inputs reveals that the Blast Furnace and Steel Mills and Petroleum Refining industries have regulatory inputs that result in decreased productivity. However, some inputs also have some positive effects on productivity. When simulating reduced regulatory inputs in the Petroleum Refining industry, productivity was increased. Therefore, the results of this study seem to show that abatement expenditures can have both positive and negative effects on productivity.

Areas for further research in this area to better estimate the relationship between environmental regulation and productivity include allowing for differences in firms when studying at the industry level. Including a variable related to compliance with environmental regulations or increases in regional regulations would study a more direct relationship between regulations and productivity as well. In addition, more detailed models of the production function for the industries are needed.

With better analysis of the costs and benefits of laws before implementation, regulations to reduce pollution can be made to minimize any negative effects they may have on productivity. Therefore it is important to transform regulation expenditures from their physical impact into their actual costs in terms of their effect on a firm's output. Also, finding direct and indirect costs associated with environmental regulation need to be defined. Once these improvements have been made, then these costs could enter into a more efficient Cost-Benefit Analysis, which is often the method used by the government in making environmental policy decisions.

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